APPARATUS, AND AN ASSOCIATED METHOD, FOR FACILITATING SYNCHRONIZATION IN A WIRELESS MESH NETWORK.

The present invention relates generally to a manner by which to facilitate time synchronization between nodes of a mesh network, such as a fixed broadband access network or a moving ad hoc mesh network. More particularly, the present invention relates to apparatus, and an associated method, by which to provide accurate time reference indicia to the nodes of the mesh network to permit time and clock synchronization pursuant to a synchronization hierarchy. Time stamps are added to data packets at a node at which an updated time reference value is maintained. When sent to another node, the time stamp is extracted to provide the other node with the updated time reference value. The time reference value is buffered and updated at a register and selectably retrieved therefrom to form the time stamp.

BACKGROUND OF THE INVENTION

Communication of data between remotely-positioned sending and receiving stations is a necessary adjunct of modern society. A wide variety of different types of communication systems have been

developed and are regularly utilized to effectuate communication of data between the sending and receiving stations.

Communication technology advancements have permitted the development, and commercial implementation, of new types of

5 communication systems. Radio communication systems are exemplary of communication systems which have benefited from the advancements in communication technologies. Improvements to existing types of radio communication systems, as well as new types of radio communication systems, have been made possible as a result of the

10 advancements in communication technologies.

Use of a radio communication system inherently permits increased communication mobility in contrast to use of a conventional wireline communication system. Communication channels defined between sending and receiving stations of a radio

15 communication system are defined upon radio links formed therebetween. The communication channels are referred to as radio channels and do not require fixed connections for their formation.

The advancements in communication technologies which have

20 permitted the development and implementation of new types of communication systems include, for instance, digital communication

techniques. The use of digital communication techniques permits

the communication capacity of a communication system to be

increased as well as also to improve the quality levels of

communications effectuated in the communication system.

5   Information which is to be communicated in a digital

communication system is digitized. Once digitized, the digitized

information is formatted, such as into packets of data, referred to

as data packets. Data packets are sent by a sending station upon

the radio channel to the receiving channel, thereby to effectuate

10   the communication of the data packets therebetween. Individual

ones, or groups, of the packets can be communicated at discrete

intervals, and, once communicated, the packets of data can be

concatenated together to recreate the informational content of the

transmitted information.

15   Because the packets of data can be sent at discrete intervals,

a radio, or other, communication channel need not be dedicated

solely for the communication of data pursuant to a single

communication session between one sending station and one receiving

station.   A dedicated channel, in contrast, is required in

20   conventional circuit-switched communications. In packet-switched

communications, a single channel can be used pursuant to the

effectuation of a plurality of different communication sessions. Improved communication capacity is possible due to the shared nature of the communication channels permitted in packet-switched communications.

5   A wireless mesh network is a radio communication system which can be constructed to provide for the communication of packet data pursuant, e.g., to a digital communication technique. A wireless mesh network typically includes a plurality of nodes, each node capable of communicating with at least one other node. A wireless mesh network is implemented, for instance, as a fixed broadband access network capable of communicating broadband data between fixed-site communication stations which form the nodes. A moving ad-hoc mesh network is also representative of a wireless mesh network.

15   Network synchronization is necessary in a wireless mesh network to properly utilize the radio resources available to communicate thereon. Transmission and reception scheduling is conventionally utilized in a wireless mesh network. Scheduling is required to ensure that the nodes of the network be synchronized in time. Through appropriate time synchronization, guard intervals separating communications upon a radio link can be reduced as the

synchronization limits the amount of drifting of bursts of packet

data beyond a defined transmission period. Without proper

synchronization, guard intervals of increased sizes are required,

thereby reducing the communication capacity upon the radio links

5   formed between nodes of the network.

In a mesh network, a formal hierarchy is not necessarily

defined. And, if a hierarchy is defined, reference distribution,

pursuant to which synchronization is performed, is implemented

hierarchically. Reference errors increase accumulatively in

10   successive branches of the hierarchically-defined structure.

A manner by which to provide a systematic reference by which

to effectuate time synchronization in a mesh network, such as a

fixed broadband access network or a moving ad-hoc mesh network

would therefore be advantageous.

15   It is in light of this background information related to

communications in a mesh network that the significant improvements

of the present invention have evolved.

SUMMARY OF THE INVENTION

The present invention, accordingly, advantageously provides

20   apparatus, and an associated method, by which to facilitate time

synchronization between nodes of a mesh network, such as a fixed

broadband access network or a moving ad-hoc mesh network.

Through operation of an embodiment of the present invention,

accurate time reference indicia is provided to the nodes of the

5   mesh network to permit time and clock synchronization pursuant to a

synchronization hierarchy.

An updated time reference value is maintained at a node of the

mesh network. The time reference value is used as a time stamp

which is added to data packets which are to be communicated by the

10   node to another node. When sent to the other node, the time stamp

is extract to provide the other node with the updated time

reference value. The time reference value is maintained at the

first node at a register and is selectably retrieved therefrom to

be used the time stamp.

15   In one aspect of the present invention, a network time

register is positioned at a first node formed of a first

communication station of the mesh network. A clock signal is

applied to the network time register, and the contents of the

network time register are incremented, either positively or

20   negatively, thereby to maintain an update at the register of an

updated time reference value. At least selected data packets are

time-stamped with time reference values retrieved from the network

time register. When the data packets are communicated to a second,

or other, node formed of another communication station, the time

stamp is extracted from the data packet and used to time

5   synchronize the other communication station to the first

communication station.

Delay between the send time, i.e., the time at which the data

packet is sent by the first communication station and the receive

time, i.e., the time at which the data is received at the second

10   communication station, is compensated for by calculation of the

transmission duration. Calculation is made by returning a data

packet from the second communication station to the first

communication station. The time at which the returned data packet

is received at the first communication station permits

15   determination of the transmit time between the two communication

stations. An additional data packet is sent to the second

communication station to inform the second communication station of

the transmission time period and the corresponding alteration of

the time reference value which should be maintained at the second

20   communication station.

In another aspect of the present invention, an additional register, a latch register, is also formed at the first communication station. The network latch register is coupled to the network time register, and time reference values buffered and

5   maintained at the network time register are also selectably storable at the network latch register. The values are retrieved and latched thereat upon application to the latch register of a trigger signal. When the trigger signal is applied to the latch register, the contents of the network time register are copied

10   thereto.

In another aspect of the present invention, a network strobe register is also formed at the first communication station. The strobe register is also coupled to the network time register to receive values of the reference time stored thereat. The strobe

15   register counts out and generates a signal which forms the trigger signal when the register counts out. Thereby, at periodic intervals, when the strobe register counts out, a trigger signal is generated and applied to latch register.

Registers, either implemented as hardware devices or as

20   software devices, formed at a communication station in a mesh network provide a manner by which to maintain, and update, a time

reference value. By time-stamping selected data packets which are

communicated by the communication station to another communication

station, time synchronization therebetween is provided. And, when

successive nodes, i.e., communication stations of the mesh network

5   include   such   registers,   network-wide   synchronization   is

implementable. A pseudo-hierarchy is also provided by defining a

one of the communication stations to maintain the reference time

value.

         In these and other aspects, therefore, apparatus, and an

10   associated method, is provided for a wireless mesh network having a

first communication station and at least a second communication

station. Time-synchronization of communication of data between the

first and least second communication stations is provided. A

network time register is coupled to receive a time reference signal

15   of values representative of a reference time. The network time

register buffers and maintains updated values of the reference

time. A data formatter is coupled to the network time register.

The data formatter formats the data to be communicated between the

first and least second communication stations of the wireless mesh

20   network. The data, once formatted, includes indicia associated

with the updated values of the reference time buffered at the
network time register.

A more complete appreciation of the present invention and the
scope thereof can be obtained from the accompanying drawings which
are briefly summarized below, the following detailed description of
the presently-preferred embodiments of the invention, and to the
appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 illustrates a functional block diagram of an
exemplary wireless mesh network in which an embodiment of the
present invention is operable.

Figure 2 illustrates a functional block diagram of exemplary
network timing circuitry of an embodiment of the present invention.

Figure 3 illustrates a functional block diagram, similar to
that shown in Figure 2, of timing circuitry of an alternate
embodiment of the present invention.

Figure 4 illustrates a functional block diagram of an
implementation of the timing circuitry of the embodiment shown in
Figures 2 and 3.

Figure 5 illustrates a functional block diagram of clock synchronization circuitry of an embodiment of the present invention.

Figure 6 illustrates a method flow diagram of the method of operation of an embodiment of the present invention.

Figure 7 also illustrates a method flow diagram, also representative of the method of operation of an embodiment of the present invention.

Figure 8 illustrates a representation of communications between first and second nodes of the exemplary wireless mesh network shown in Figure 1.

DETAILED DESCRIPTION OF THE INVENTION

Referring first to Figure 1, an exemplary wireless mesh network, shown generally at 10, provides for wireless communications between a plurality of nodes 12 which collectively

5   form the mesh network. In the exemplary implementation, the wireless mesh network forms a fixed wireless broadband access network. In another implementation, the mesh network 10 is representative of a mobile ad-hoc network.

Each of the nodes 12 forms a wireless communication station

10 capable of transceiving communication signals with other communication stations. When the mesh network provides for packet data communications, the communication stations are operable to communication packet data therebetween.

While a mesh network does not necessarily contain a hierarchy,

15 the mesh network 10 shown in the figure defines a pseudo-hierarchy relative to a center (as-shown) communication station 12-C. The communication station 12-C forms a reference node. Distances from the reference node from other nodes are defined in terms of hops.

With respect to the reference node 12-C, a first set of nodes

20 formed of communications, in here shown at 12-1 are positioned at one-hop distance from the reference node 12-C. Another set of

communication stations formed for the nodes, here shown at 12-2, are two-hop distances from the reference node 12-C. And, a third set of communications stations formed of the nodes, and here shown at 12-3 are at three-hope distances from the reference node 12-C. Nodes 12-4 and 12-5 are analogously numbered responsive to their respective hop distances from the reference node.

    While only a single reference node 12-C is represented in Figure 1, a pseudo-hierarchy formed of multiple references can also be defined in a wireless mesh network. In such an implementation, the simplistic hop-distribution shown in Figure 1 with respect to a signal reference node is not utilized. But, in such an implementation, a single node synchronizes, for example, to its neighbors with a lowest distance to a reference node.

    To provide for efficient utilization of the radio resources allocated to the mesh network, appropriate levels of time synchronization are required to be effectuated in the mesh network. An embodiment of the present invention provides for time and clock synchronization pursuant to a pseudo-hierarchy which provides appropriate levels of synchronization between the nodes of the mesh network to permit efficient synchronization of the radio resources allocated to the network. The manner by which the synchronization

is provided permits a mesh network utilizing more than one
synchronization source to effectuate time synchronization as well
as also to provide a reference to various destination nodes.

Figure 2 illustrates timing circuitry, shown generally at 20,

5   of an embodiment of the present invention. The timing circuitry is
functionally represented and can be implemented in any desired
manner, both software implementations, hardware implementations,
and combinations both hardware and software implementations. In
the exemplary implementation, the timing circuitry 20 is

10 implemented at one or more of the nodes of the of the mesh network.
In the implementation shown in Figure 1 which shows a signal
reference formed of the communication station forming the node 12-
C, the timing circuitry is formed at least at the reference node
12-C. To permit synchronization of data packets communicated over

15 several hops between nodes, other of the communication stations
forming others of the nodes also includes the timing circuitry 20.

The circuitry 20 includes a network time register 22 of a
register size capable of buffering a clock value which defines a
reference time. An input clock signal here generated on the line

20 24 is applied to the register 22 to alter the buffered time
reference value stored in the register.

Time reference values maintained at the register 22 are
accessible, here by a data formatter 26 to retrieve the reference
values buffered at the register 22 and to add values representative
of the time reference values to data packets into which data
5   formatted by the data formatter is formatted. The time reference
values form time stamps. And, the time stamp is representative of
a reference time and is included in the header portion of outgoing,
or incoming, data packets. When added to an outgoing data packet,
the time stamp information is added into the packet, and when added
10   into an incoming data packet the time stamp information added as a
separate indication of the reception time at which the data packet
is received at the node at which the circuitry 20 is formed.

The time reference value buffered at the network time register
22 is incremented for each clock cycle of the clock signal applied
15   thereto. Not all of the least significant bits of the buffered
value need to be available if the precision time stamp value to be
added to a data packet does not require that the least significant
bit, or bits, be used. By selectably selecting the number of bits
to be used in the time stamping function, the circuitry 20 can be
20   used over a broad range of frequencies, enabling different kinds of
reference signals.

The circuitry 20 further includes a latch register 32. The
latch register is coupled to the network time register 22 and is
selectably operable to retrieve and latch in the latch register a
time reference value buffered and maintained at the register 22.

5   The latch register latches a value of the time reference value
buffered at the register 22 upon application of a trigger signal
thereto on the line 34. Upon application of the trigger signal on
the line 34 to the latch register 32, the contents of the network
time register 22 are copied into the latch register 32 and

10   maintained thereat. When the trigger signal is generated upon the
occurrence of a selected event, the time reference valued stored at
the latch register is representative of the time of occurrence of
the selected event. Thereby, an accurate reading of when a certain
event occurred is stored at the latch register 32. Access to the

15   time of occurrence of the event is available for subsequent
analysis or processing.

Several output sources are able to be synchronized to a single
input source thereby. The input source would, e.g., become a
master of the network time register 22. Each of the time stamping

20   circuitry of the respective output sources are accessible to the
network time register 22 in manners analogous to the manner by

which the time stamp circuitry of the data formatter 26 shown in

Figure 1 is capable of accessing the time reference value buffered

at the network time register 22.   If the output sources are

positioned at different devices, such as on different integrated

5   circuitry chips or different integrated circuitry boards,

synchronization is obtained by providing the clock signal generated

on the line 24 and the trigger signal applied on the line 34 on

each of the output sources. The clock signal generated on the line

generated on the line 24 provides a time base. And, by generating

10   the trigger signal upon the occurrence of the selected event, a

time reference value is latched at the latch register.

Figure 3 illustrates the timing circuitry of a further

embodiment of the present invention. Again, the timing circuitry

includes the network time register 22 and the latch register 32.

15   And, the network time register is coupled to a data formatter 26

which includes time stamping circuitry for selectably time stamping

selected data packets. The line 24 upon which the clock signal is

generated for application to the register 22 is again shown.

Here, the timing circuitry 20 further includes a strobe

20   register 42. The strobe register 42 is coupled to the network time

register and selectably buffers a value retrieved from the network

time register thereat.   When the register counts out, a strobe

signal is generated on the line 34 which forms the trigger signal

which is applied to the latch register 32.   In this implementation,

the trigger signal causes a value of the period length between the

5   generation of two trigger signals to be written into the register

32, and the trigger signals are generated periodically with a high

degree of accuracy.

Figure 4 illustrates circuitry 40 representative of a

multiple-device configuration in which the timing circuitry shown

10   in Figures 2 or 3 are implemented.   Here, a clock oscillator in

which the timing circuitry shown in Figures 2 or 3 are implemented.

Here, a clock oscillator 41 generates a clock signal on the lines

24 which are applied to clock pins 42 at circuit devices 44, 46 and

48.   A trigger signal, generated at the circuit device 48 is

15   applied to strobe pins 52 of the devices 46 and 48.   The circuit

devices 44, 46, and 48 are representative of any of a large variety

of devices, such as a radio interface, ethernet and a GPS (global

positioning system) receiver.

Figure 5 illustrates clock synchronizations circuitry 60 which

20   includes the timing circuitry 20 shown previously in Figures 2 and

3.   Here, a reference clock signal is generated by a voltage-

control clock oscillator (VCXO) 62. The clock signal is applied to

the timing circuitry 20. And, time stamping is provided by the

timing circuitry. The circuitry 60 also includes interface

circuitry 64 which generates a biasing signal on the line 66 for

5   application to the clock oscillator. The physical interface

circuitry 64 tracks the frequency of an incoming signal. If the

incoming signal is a synchronization reference signal, a biasing

signal is generated on the line 66 to alter the oscillation

frequency of the clock oscillator 62. When the oscillation

10   frequency of the reference clock signal is corrected, the correct

reference clock frequency is obtainable from the physical signal

itself, or at least a calculation of the offset. When the

reference clock biasing is available, the device is capable of

adjusting its own reference to match the reference of the network.

15   Figure 6 illustrates a method flow diagram, shown generally at

70, of the method of operation of an embodiment of the present

invention by which to time stamp a data packet with a time

reference value buffered and maintained at a network time register

22 (shown Figures 2 and 3).

20   First, and as indicated by the block 72, transmission of data

packets between first and second communication stations formed of

nodes of a wireless mesh network is initiated. As indicated by the

block 74, a burst of data packet is generated. Then, and as

indicated by the decision block 76, a determination is made as to

whether a time stamp is to be added to a data packet of the burst.

5   If so, the yes branch is taken to the block 78 and a time stamp is

added to the data packet. If, conversely, a time stamp is not to

be added to the data packets of the burst, no branch is taken to

the decision block 82. A path is also taken from the block 78 to

the decision block 82.

10   At the decision block 82, a determination is made as to

whether hop information is to be also added to a data packet. If

so, the yes branch is taken to the block 84, and a hop value

associated with a number of hops is added to the data packet. A

branch is then taken to the decision block 86. If, conversely, hop

15   information is not to be added to the data packet, the no branch is

also taken to the decision block 86.

At the decision block 86, a determination is made as to

whether event timing information is to be added to the data packet.

If so, the S branch is taken to the block 88, and timing

20   information is added to the data packet, and a branch is taken to

the block 92. If the no branch is taken from the decision block

86, a branch is also taken to the block 92. At the block 92, the

data packet burst is transmitted. Then, a path is taken to the end

block 94.

Figure 7 illustrates a method, shown generally at 100, of an

5   embodiment of the present invention by which to utilize a time

stamp added to a data packet which is received at a second

communication station forming a node of a mesh network, such as a

mesh network shown in Figure 1. The time stamp information is

utilized to synchronize the second communication station to the

10   first communication station from which the data packet is sent.

First, subsequent to the start reception block 102, a data

burst is received, indicated by the block 104. A receive time

stamp is added to the data packet, indicated at the block 106, to

identify the reception time at which the data packet of the data

15   burst is received.

Then, and as indicated at the decision block 108, a

determination is made as to whether an attempt should be made to

synchronize the second communication station to the first

communication station. If no attempt is to be made, the no branch

20   is taken to the end block 112. Otherwise, the yes branch is taken

to the block 114 and a hop value is extracted from the data packet.

Then, and as indicated by the block 116, a determination is made as

to whether the source of the burst of data packets is the reference

in a pseudo-hierarchical structure defined in the mesh system. If

not, the no branch is taken to the end block. Otherwise, the yes

5   branch is taken to the block 118 and the transmit time stamp

contained in the data packet is extracted. Then, and as indicated

by decision block 122, a determination is made as to whether timing

information related to the occurrence of an event is available. If

so, the yes branch is taken to the block 124 and the timing

10 information is extracted from the data packet. Then, a branch is

taken to the block 126. The no branch from the decision block 122

is also taken to the block 126.

At the block 126, the time stamps are compared. Then, at the

decision block 128 a determination is made as to whether the time

15 stamps correspond. If so, the yes branch is taken to the end block

112. Otherwise, time synchronization is performed by taking the no

branch to the block 132 and the timing information at the second

communication station is set using the time information extracted

from the data packet received at the communication station.

20   Figure 8 illustrates signaling between two of the

communication stations forming nodes in the mesh network 10 shown

in Figure 1 pursuant to synchronization operations effectuated

during operation of an embodiment of the present invention. Here,

data packets are communicated between the reference node 12-C and a

node 12-1 positioned at a one-hop distance away from the reference

5   node. A data burst including at least one data packet to which a

time stamp has been added in manners as above described, is sent by

the reference node to the 12-C, as indicated by the arrow 122. The

data packet is received at the node 12-1, and the time stamp

information is extracted therefrom, also as described above. An

10   acknowledgment burst is returned by the node 12-1 to the reference

node 12-C, here indicated by the segment 124. By providing the

acknowledgement burst back to the reference node, the propagation

delay in the propagation of the data from the reference node to the

node 12-1. When the acknowledgement packet is received at the

15   reference nodes 12-C, a cumulative timing error corresponding to

twice the propagation delay is contained in the signal. The

reference node is able to calculate the propagation delay

responsive to the timing information contained in the

acknowledgement packet and thereafter generate a message, here

20   represented by the segment 126, which includes a correction factor

correcting for the propagation delay.   Thereby, the node 12-1

becomes completely time synchronized with the reference node.

Multiple-hop communication of a data packet between successive

nodes of the mesh network shown in Figure 1.

5   Transmission of the data packet occurs during a time slot.

First, for instance, the reference node 12-C is sent to a node 12-

1.   The transmission of the data packet is advanced by the

propagation time required to transmit the data packet to the nodes

12-1.   The packet transmission is initiated prior to the start of

10 the slot.   The node 12-1 passes on the data packet to a subsequent

node, e.g., a node 12-2.   And, transmission by the node 12-1 occurs

at the start of the time slot due to the propagation delay in

transmission from the reference node to the node 12-1.   Then, once

received at the subsequent node 12-2, the data packet is forwarded

15 on to another of the nodes, e.g., a node 12-3.   The propagation

delay in communication of the data packet between the nodes 12-1

and 12-2 causes additional delay prior to forwarding the data

packet to the node 12-3.

Thereby, through operation of an embodiment of the present

20 invention, a manner is provided by which to provide accurate time

reference indicia to the nodes of the mesh network to permit time

and clock synchronization pursuant to a pseudo hierarchy using one

or more references.

The previous descriptions are of preferred examples for

implementing the invention, and the scope of the invention should

5   not necessarily be limited by this description. The scope of the

present invention is defined by the following claims.